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Control of Volatile Organic Emissions from Existing Stationary Sources. Volume III Surface Coating of Metal Furniture

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GUIDELINE SERIES

CONTROL OF VOLATILE ORGANIC EMISSIONS FROM EXISTING STATIONARY SOURCES VOLUME III: SURFACE COATING OF METAL FURNITURE

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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This report provides the necessary guidance for development of regulations to limit volatile organic compound (VOC) emissions from the coating operations of metal furniture industry. This guidance includes an emission limit which represents Reasonably Available Control Technology (RACT), methods by which RACT can be achieved, and monitoring and enforcement aspects.

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Emissions Standards and Engineering Division
Chemical and Petroleum Branch

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1977

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OAQPS GUIDELINE SERIES

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PREFACE

This document is one of a series designed to inform Regional, State and local air pollution control agencies of techniques available for reducing emissions of volatile organic compounds (VOC) from existing stationary sources. It deals with the surface coating of metal furniture. "Metal furniture" includes any furniture made of metal or any metal part which will be assembled with other metal, wood, fabric, plastic or glass parts to form a furniture piece. This document describes the industry, identifies sources and types of emissions, and applicable methods and costs of reducing these emissions. It also discusses techniques for monitoring the organic solvent content of coatings for purposes of determining compliance with anticipated regulations. Detailed discussions on low organic solvent coatings and add-on control technologies are found in "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume I: Control Methods for Surface Coating Operations."[1] ASTM test methods for monitoring organic solvent technology are found in "Volume II: Surface Coating of Cans, Coil, Paper, Fabric, Automobiles and Light Duty Trucks,"[2]

The table below provides emission limitations that represent the presumptive norm which can be achieved through the application of reasonably available control technology (RACT). Reasonable available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may

[1] EPA-450/2-76-028, November 1976, (OAQPS No. 1.2-067)
[2] EPA-450/2-77-008, May 1977, (OAQPS No. 1.2-073)

require technology that has been applied to similar, but not necessarily identical source categories. Since the definition of metal furniture includes a wide variety of products, it must be cautioned that the emission limits reported in this Preface are based on capabilities which are general to this industry, but may not be applicable to every facility.

Affected Facility	Recommended Limitation	
	kg of organic solvent emitted per liter of coating (minus water)	lbs of organic solvent emitted per gallon of coating (minus water)
Metal Furniture Coating Line	0.36	3.0

This emission limit is based on the use of low organic solvent coatings. It can also be achieved with water-borne coatings and is approximately equivalent (on the basis of solids applied) to use of an add-on control device which collects or destroys about 80 percent of the solvent from a conventional high organic solvent coating. Even greater reductions (up to 90 percent) can be achieved by installing new equipment which uses powder or electrodeposited water-borne coatings. It is believed that most metal furniture facilities will seek to meet future regulations through the use of coatings which are low in organic solvent.

GLOSSARY

- Prime coat means the first film of coating applied in a two-coat operation.
- Topcoat means the final film of coating applied in a two-coat operation.
- Single coat means only one film of coating is applied on the metal substrate.
- Faraday caging means a repelling force generated during electrostatic spraying of powders in corners and small enclosed areas of metal substrate.
- Blocking agent means an agent which is released from the polymer matrix during the curing process. It is normally an organic radical and splits from the monomer or oligmer at a predetermined temperature, thereby exposing reactive sites which then combine to form the polymer. Such reactions during the curing process may release additional volatile organic compounds into the atmosphere.
- Low organic solvent coating refers to coatings which contain less organic solvent than the conventional coatings used by industry. Low organic solvent coatings include water-borne, higher-solids, electrodeposition and powder coatings.

CONVERSION FACTORS FOR METRIC UNITS

Metric Unit	Metric Name	Equivalent English Unit
Kg	kilogram (10^3 grams)	2.2046 lb
liter	liter	0.0353 ft^3
dscm	dry standard cubic meter	35.31 ft^3
scmm	standard cubic meter per min.	35.31 ft^3/min
Mg	megagram (10^6 grams)	2,204.6 lb
metric ton	metric ton (10^6 grams)	2,204.6 lb

In keeping with U.S. Environmental Protection Agency policy, metric units are used in this report. These units may be converted to common English units by using the above conversion factors.

Temperature in degrees Celsius (C°) can be converted to temperature in degrees Farenheit (°F) by the following formula:

$t°_f = 1.8\ (t°_c) + 32$

$t°_f$ = temperature in degrees Farenheit

$t°_c$ = temperature in degrees Celsius or degrees Centigrade

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1.0 SOURCES AND TYPES OF EMISSIONS

This chapter provides a general introduction to the metal furniture industry, the methods by which conventional solvent-borne coatings are applied, and volatile organic solvent (VOC) emissions which can be expected from these coatings.

1.1 GENERAL DISCUSSION

Metal furniture is manufactured for both indoor and outdoor use, and may be divided into two general categories; "business and institutional", and "household." Business and institutional furniture is manufactured for use in hospitals, schools, athletic stadiums, restaurants, laboratories and other types of institutions, and government and private offices. Household metal furniture is manufactured mostly for home and general office use. Although there are more than twice as many manufacturers of metal household furniture, on the average, those that manufacture metal business and institutional furniture are twice as large. About half of the metal household furniture manufacturers employ less than 20 employees.[1] Metal furniture includes a variety of items including tables, chairs, waste baskets, beds, desks, lockers, benches, shelving, file cabinets, lamps, room dividers and many other similar products.

Metal furniture plants are located throughout the United States, however, Illinois, California, Michigan, New York and Pennsylvania contain over 50 percent of the plants in the industry. The Environmental Protection Agency's Region V contains about 30 percent of the industry, Regions II and IV about 16 percent each, and Regions III and IX about 11 percent each. Plants vary

in size depending on the type of furniture manufactured, the number of manufacturing and coating lines, and the amount of assembly required. The manufacturing markets of metal furniture facilities vary. Some plants manufacture metal furniture to be sold directly to consumers through retail stores. In contrast, "job shops", produce furniture on contract. The latter facilities apply coatings on many different furniture pieces according to the customer's specifications. The size of a metal furniture coating line varies depending on the furniture coated, the type of coating application used, and on how many coats are applied. The coating line can have a steady production rate ranging from 8 to 24 feet per minute, or the furniture pieces may be coated sporadically.

Coatings applied in each plant vary with personal preference, type of furniture, application technique, pretreatment, and end use. Conventional coatings are applied at 0.7 to 1.5 mils thickness. Most of the coatings are enamels although some lacquers are also used. Some metal furniture pieces are coated with metallic coatings. The most common coatings are alkyds, epoxies and acrylics containing various mixtures of ketones, aromatic, aliphatic, terpene, ester, ether and alcohol solvents. The coatings are often purchased at higher solids contents but are thinned for application to about 25 to 35 volume percent solids.

The coatings applied to metal furniture must protect the metal from corrosion, be it indoor or outdoor furniture. They must have good adhesion properties to avoid peeling or chipping, must be durable and must meet customer standards of appearance.

1.2 PROCESSES AND EMISSION POINTS

Figure 1-1 depicts a typical metal furniture line. Unassembled, semi-assembled or totally assembled furniture pieces first are transported on a conveyor through a cleansing process. Here an alkaline cleaner removes mill scale, grease and oil. After a hot rinse, iron phosphate or other pretreatment often is employed to improve coating adhesion and prevent rusting. Following a cold rinse, the pieces are dried at 130°-180°C (250°-350°F). In some cases, the entire wash section is omitted and the pieces are cleaned in a shot-blasting chamber or organic solvent cleaning operation.

Most metal furniture is finished with a single-coat operation. Some pieces, however, require a prime coat application due to the topcoat formulation or the end-use of the piece. The prime coat may be applied by electrostatic or conventional spray, dip or flowcoating techniques. The substrate with the prime coat then goes through a flashoff period to avoid popping of the film when the coating is baked. The prime coat is usually baked in an oven at about 160° to 200°C (300°-400°F).

The topcoat or a single coat may be applied by spraying, dipping or flowcoating. If a plant manufactures furniture in a variety of colors, necessitating frequent color changes, the coating is usually sprayed either electrostatically or by conventional airless or air spray methods. If a plant manufactures furniture in only one or two colors, the coating often is applied either by flowcoating or by dipping.

Electrostatic spray coating may be performed either manually or automatically although most spray coating in metal furniture facilities is done manually. The paint particles are negatively charged, move along the path

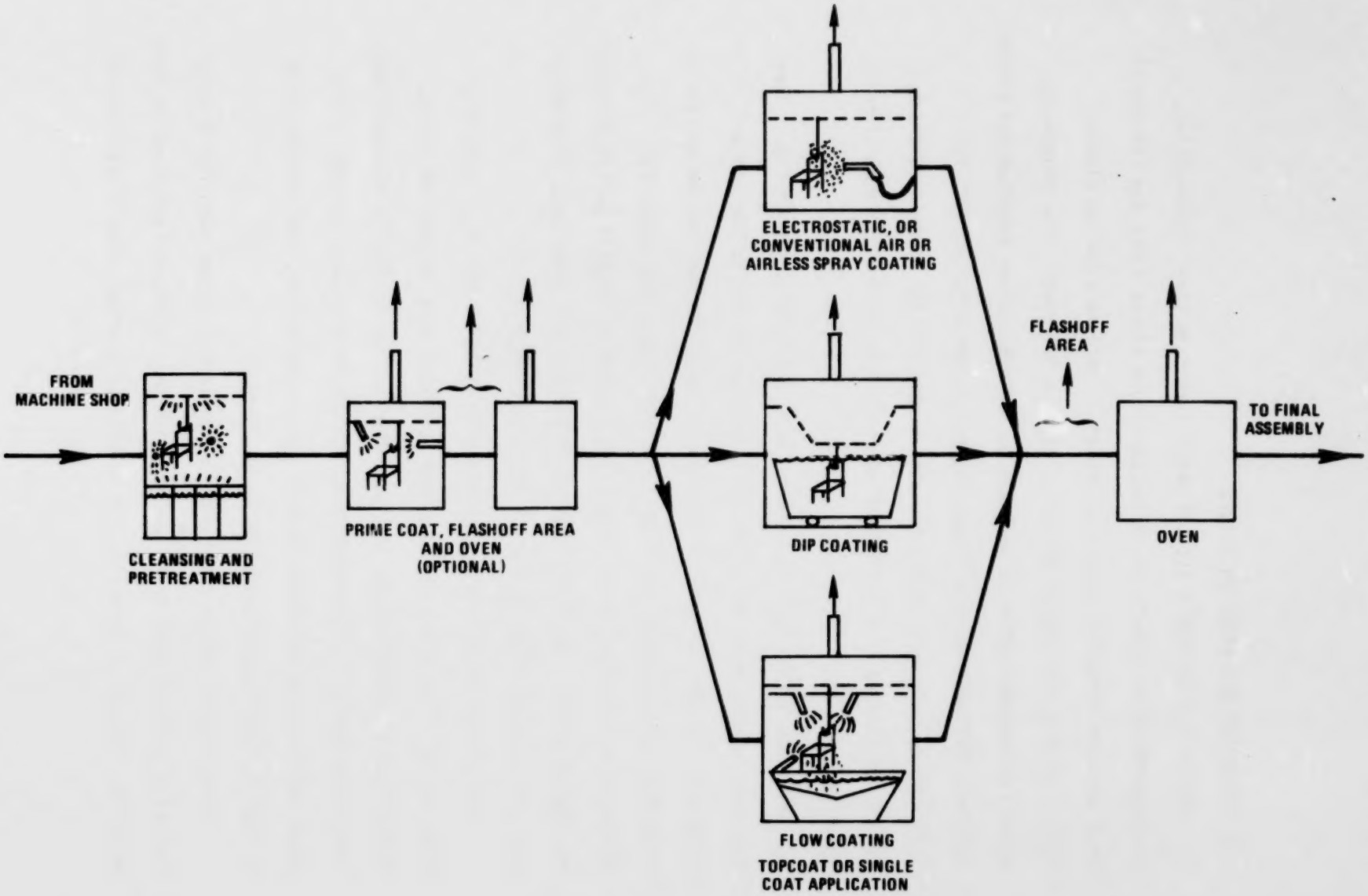

Figure 1-1 Common techniques used in the coating of metal furniture pieces.

of an electric force field created between the spray gun and the grounded metal furniture piece, and coat the piece. This method of application is more efficient than the conventional air or airless spray methods because there is less overspray thereby reducing the amount of paint that must be sprayed and the VOC that evaporates.

Spray coating is performed in a booth to contain overspray and prevent surface contamination. Two kinds of spray booths are usually found in the metal furniture industry, down draft or side draft. Air flow rates from spray booths vary depending on whether it is occupied by people, on type of spray booth, and on size of spray booth and openings. The minimum air velocities are prescribed by OSHA to assure capture of paint particles and insure the VOC concentration does not exceed the threshold limit values.

Dip coating is the immersion of pieces into a coating bath. After withdrawal, the excess coating is allowed to drain back into the tank.

Flowcoating involves conveying the piece over an enclosed sink, and allowing pumped streams of coating to hit the piece from all angles, flow over the piece and coat it. Excess coating drains back into the sink, is filtered and pumped back into a coating holding tank.

The coated furniture is usually baked in an oven but in some cases is air dried. The flashoff area lies between the coating application area and the oven. This allows solvents to rise slowly in the coating film, thus avoiding popping of the film when the coating is baked. The fraction of the solvent which evaporates in this area will depend on the type of coating used, line speed and the distance between the application area and oven.

The baking oven may contain several zones at temperature ranges of 160° to 230°C (300-450°F). The exhaust air flow rate from the ovens will depend on the type and size of the oven, and the size of the oven openings through which the parts enter and exit. Fire Underwriters Insurance typically requires that the atmosphere within industrial baking ovens not exceed 25 percent of the lower explosive limit (LEL) of the evaporating solvents. This means that about 10,000 scf of air is required to evaporate 1 gallon of solvent. Some facilities have been allowed to operate at higher LEL's (around 50 percent), however, if proper LEL monitoring equipment is used. Many metal furniture baking ovens presently operate between 5-15 percent of the LEL. The principle reason for maintaining such low concentration levels is that the oven must be maintained under negative pressure to avoid spillage of fumes into the plant. This requires a 15 mpm (50 fpm) to a 45 fpm (150 fpm) air velocity through the oven openings. The lower velocities are common to ovens which use air curtains to contain spillage. Since the openings are often large to accommodate the variety of coated metal furniture pieces, the air flow required to maintain the oven under negative pressure may exceed the air flow required to maintain the oven below 25 percent LEL.

Volatile organic compounds are emitted from the coating area, the flash-off area and the oven. It is estimated that in spray applications, about 65-80 percent of the VOC are released from the spray booth and the flashoff area, and the remaining 20-35 percent from the oven. For a dip or flowcoat application, it is estimated that about 50-60 percent of the VOC are emitted from the coating and flashoff area, and the other 40-50 percent from the oven.

Table 1-1 summarizes estimated VOC emissions from metal furniture coating operations. Note that emissions will vary from line to line due to its construction and the type of coating applied.

Figure 1-2 displays the relationship between VOC emissions and flowrate with isopleths of organic concentrations (LEL). Note that for a given emission rate, the exhaust flowrate at one percent LEL concentration is 10 times that at 10 percent LEL. The flowrate and resulting concentrations are a function of many factors; open or enclosed spray booths, dip or flowcoater, flashoff area or an oven. Unfortunately, flowrates are often designed for the worst situation and may be excessive for the typical piece coated by the facility.

Table 1-1 DISTRIBUTION OF VOC EMISSIONS[a] FROM METAL FURNITURE COATING LINES

Application Method	Application and Flashoff Area	Oven
Electrostatic Spray	65	35
Conventional Air or Airless Spray	80	20
Dip	50	50
Flow	60	40

[a] The base case coating is applied at 25 volume percent solids, 75 volume percent organic solvent which is equivalent to a VOC emission factor of 0.66 kg of organic solvent per liter of coating (5.5 lbs/gal) minus water.

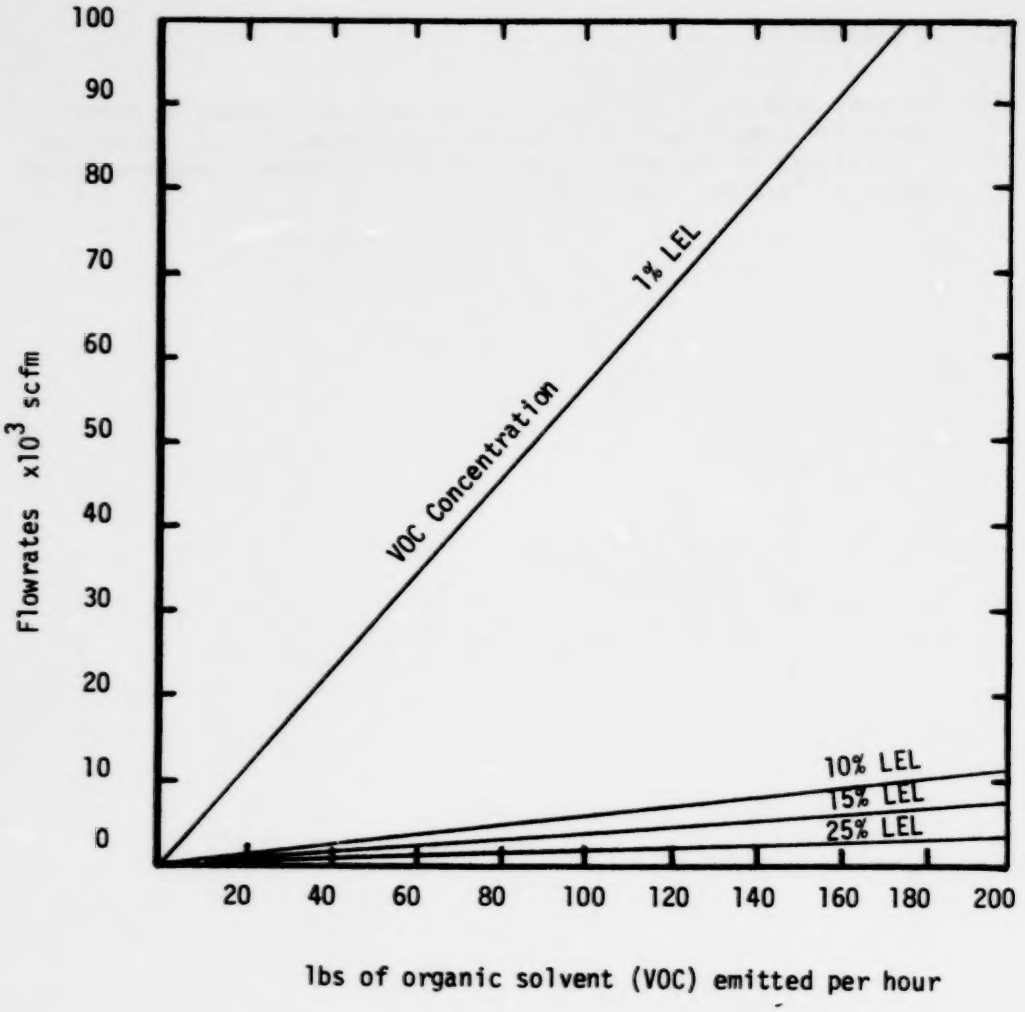

Figure 1-2. Relationship between VOC emission, exhaust flowrates and VOC concentrations.

1.3 REFERENCES

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2.0 APPLICABLE SYSTEMS OF EMISSION REDUCTION

This chapter discusses low polluting coatings and add-on equipment for the control of VOC from conventional coating applications used in the metal furniture industry. It also discusses other methods of applying coatings (powder and electrodeposition) which result in low VOC emissions.

Table 2 SUMMARY OF APPLICABLE CONTROL TECHNOLOGY FOR METAL FURNITURE

Control Technology	Coating Application	Percent Reduction In Organic Emissions
Powder (spray or dip)	Top or single coat	95-99[a]
Water-borne (electro-deposition)	Prime or single coat	90-95[a]
Water-borne (spray, dip or flowcoat)	Prime, top or single coat	60-90[a]
Higher solids (spray)	Top or single coat	50-80[a]
Carbon adsorption	Prime, top or single coat (application and flashoff areas)	90[b]
Incineration	Prime, top or single coat (ovens)	90[b]

[a]The base case against which these percent reductions were calculated is a high organic solvent coating which contains 25 volume percent solids and 75 volume percent organic solvents. The transfer efficiencies for liquid coatings were assumed to be about 80 percent for spray and 90 percent for dip or flow-coat, for powders about 93 percent, and for electrodeposition 99 percent.

[b]This percent reduction in VOC emissions is only across the control device, and does not take into account the capture efficiency.

2.1 POWDER COATING

Powder coatings may be applied electrostatically by spraying or dipping, or by dipping the preheated metal into a fluidized bed. Electrostatic spraying of powder is used more widely in metal furniture than fluidized bed because of its ability to coat the pieces with thinner films of coating. Electrostatic sprayed powders can be applied at film thicknesses of 2 mils or greater while fluidized bed powders are limited to 6 mils or greater. After application, the powder particles are melted and cured in the oven to form a continuous, solid film. Although powders appear to be 100 percent solids, it is not unusual for them to contain small quantities of entrapped organic solvent. Powders can release up to 10 weight percent of VOC during the curing process.[1] Therefore, the reduction in emissions for powders may range from 95 to 99 percent over conventional systems. Powder coatings are presently being applied on some furniture such as outdoor and indoor furniture, bed and chair frames, shelving and stadium seating.[2,3,4]

Electrostatic powder spray coating may be performed either manually or automatically. Powder particles are charged as they pass through the spray gun, and subsequently are attracted to the grounded metal furniture piece. The powder can wrap around the edges of complicated forms and is self-leveling on flat pieces. Film thickness may be controlled by voltage, and a thickness of 3 to 4 mils can easily be achieved. Film thicknesses of 2 to 3 mils can be achieved with special attention and a very close control. Thinner films, however, have been achieved only in the laboratories and not on production lines.[5]

Powder spray coating requires a booth as does spray coating with conventional coatings. However, ventilation requirements are greatly reduced from those of solvent borne spray booths mainly because the booths are not occupied. This obviates the need to heat or air condition air going into the

spray booth and saves energy. Most powder overspray may be reclaimed and reused. Some overspray, however, has to be removed and reprocessed because it consists of larger and heavier granules which are not suitable for reuse.[6] The ability to collect overspray can provide a high coating utilization. To change colors in a powder coating system, the booth and recovery units must be cleaned thoroughly to avoid color contamination. To shorten the time required for a color changeover, some plants have several recovery units that may be easily connected to the spray booth. Some have also purchased multiple mobile spray booths with associated recovery equipment.

Powder coating may also be applied by dipping metal pieces into a fluidized bed. In the metal furniture industry, dipping has the disadvantage of applying powder only in thick films (at least 6 mils). The metal furniture piece is preheated to the melting point of the powder, dipped into the bed and held there until the desired film thickness is achieved. In electrostatic fluid bed coating, the powder particles are charged and become attracted to the grounded,usually unheated,metal piece moving through the bed. The latter method is limited to simple shapes.

Powder coatings are baked at temperatures of 180° to 230°C (300-450°F). Since the concentrations of organics are almost insignificant compared to conventional coatings and no flashoff zones are required, smaller ovens may be installed. Further technical details on the use of powder coatings may be found in Volume I, Sections 3.3.3 and 3.3.5.[7]

2.2 ELECTRODEPOSITION

Electrodeposition (EDP) is being used at several facilities to coat metal furniture with 0.5 to 1.2 mils of film thickness.[8,9,10] The thickness may be adjusted somewhat by varying voltage and immersion time. Electrodeposition

provides increased corrosion protection and applies thin coatings more uniformly and at a greater transfer efficiency than any other application system. Although electrodeposition was previously limited to one to two colors, a new installation will be applying four different colors.[11]

EDP coatings are applied from an aqueous bath which contains about 10-15 volume percent solids and 2-4 volume percent organic solvents. A direct current is applied in the bath causing the solids to become attached to the grounded metal piece. Electrodeposition can be performed either anodically or cathodically. The metal emerges from the bath with a coating containing about 90 volume percent solids, 1 to 2 percent organic solvent and the balance water. It is rinsed to eliminate excess paint particles and baked at 160° to 180°C (300-350°F). The rinsing water is often obtained from the discharge from the ultrafilter. Ultrafiltration purges most of the soluble organics, amines and contaminating ions from the rinse residue and returns the solids portion to the bath.

For further technical details in the use of electrodeposition coating technology, see Volume, Section 3.3.1.[12]

2.3 WATER-BORNE - SPRAY, DIP OR FLOWCOAT

Since water-borne coatings have similar characteristics to organic solvent-borne coatings, they can often be substituted for existing solvent-borne coatings without requiring major changes to existing coating equipment. There may be however, some necessary alterations in equipment or the coating line to protect the equipment from corrosion, to lengthen the flashoff area and sometimes to control the humidity in the application and flashoff areas. Several metal coating facilities have been successful in converting their existing flow, dip and spray (both electrostatic and conventional) operation to apply water-borne coatings.

Some organic solvents must be a part of a water-borne coating to temper the evaporation rate,and to provide film coalescence and the necessary film properties. A reduction of 60-90 percent in VOC emissions may be obtained by conversion to a water-borne coating.

Water-borne coatings may be sprayed electrostatically on small coating lines if the entire coating system is electrically isolated. On larger lines, however, where the paint storage areas are hundreds or even thousands of feet away from the application areas, electric isolation of the entire system becomes difficult and sometimes financially impractical.[13,14] Color changes often require only that the application system be flushed out with water. Coating with water-borne coatings may require more attention to the coating process since temperature, humidity, gun-to-metal distance and flashoff time may change the looks and performance of the coating. Conventional air and airless spray techniques may also be used to apply water-borne coatings. Further technical details on the use of water-borne coatings may be found in Volume I, Sections 3.3.1 and 3.3.5.[15]

2.4 HIGHER SOLIDS SPRAY

The achievable VOC emission reduction by switching to higher solids coatings may range from 50 to 80 percent depending on the type of coating used previously and the volume percentage of solids. Higher solids coatings are being used on both pilot and full production lines.[16]

Higher solids coatings can be applied most efficiently by automated electrostatic spraying although manual and conventional spraying techniques can also be used. Some minimal increase in energy may be required to raise the pressure of the spray gun, heat the coating, or power electrostatic spray

equipment in order to pump and atomize these coatings due to their higher viscosities.[17] Transfer efficiencies of higher solids coatings are often better than those of conventional coatings, particularly when sprayed electrostatically.[18]

As the solids content is increased in a coating, less solvent is released for each dry mil of coating. This may permit some reduction in air flow to the booth (if the air flow was originally determined by the threshold limit of organic solvents) resulting in an energy savings.[19] This reduction however, will be limited by the successful collection of overspray particles. The lower solvent content may also allow the air flow from the oven to be reduced.

Further technical details on the use of high solids coatings may be found in Volume I, Section 3.3.2.[20]

2.5 CARBON ADSORPTION

As discussed in Chapter 1, from 50 to 80 percent of the volatile organic compounds from metal furniture coatings are emitted from the application and flashoff areas. The use of carbon adsorption can reduce emissions from these areas by 75 to 90 percent depending on the capture efficiency into the control device.

Carbon adsorption is considered a viable control option for the application and flashoff areas because exhaust gases are at ambient temperature and contain only small amounts of particulate matter that could contaminate the carbon bed. Although there are no known installations of a carbon adsorption system in a metal furniture plant, it is technically feasible,[21] and no new invention would be required. Pilot studies will be necessary, however.

The size of a carbon adsorption unit is dependent on the exhaust flow rate, its desorption period and VOC concentration. The flow rates and volatile organic concentrations will vary from each facility because of the wide variety of metal furniture manufactured. If any reduction in the flow rate of the exhaust air (within compliance with safety regulations) can be achieved, a smaller and less expensive carbon adsorber can be used. This reduces both capital and fixed operating costs. In order to optimize application of an add-on control device, the flashoff areas must be enclosed to minimize intrusion of air.

In conventional spray booths, some particulate matter from overspray is captured by dry filters, or water or oil wash curtains at about 95 percent efficiency.[22] Additional particulate removal, however, may be necessary to prevent contamination of the carbon bed. Although there is little possibility that the recovered solvents may be directly recycled (because of the complex solvent mixtures), they may be valuable as supplementary fuel for boilers or heaters.

Carbon adsorption systems can be large and require a large amount of floor space. Some large metal furniture facilities may require several dual-bed carbon adsorption units in parallel operation. Availability of the requisite space is an important consideration. The metal furniture operator may have to construct an addition to the plant.

Further technical details on the use of carbon adsorption may be found in Volume I, Section 3.2.1.[23]

2.6 INCINERATION

There are no serious technical problems associated with the use of either catalytic or noncatalytic incinerators on metal furniture facilities. Incineration has been used to reduce VOC emissions from ovens in metal furniture facilities.[24]

Incinerators are more efficient than carbon adsorbers for reducing VOC emissions from metal furniture ovens. Although some energy is required to bring the oven exhaust to incineration temperature, this incremental energy can be minimized by the use of primary heat exchangers. The concentration of organic vapors is usually higher in the oven exhaust (5-15 percent of LEL) than in the application and flashoff areas and provides some fuel for the incinerator. Particulate and condensible matter that is often found in the exhaust from higher temperature baking ovens will not affect an incinerator, whereas, it will coat a carbon bed and render it ineffective. Incineration can also be used to reduce VOC from application and flashoff areas. It will normally be necessary (but not always possible) for the operator to incorporate heat recovery systems to reduce fuel consumption to an acceptable level. Otherwise incineration of ambient temperature, low VOC concentration, gas streams is often energy intensive.

If the exhaust rate can be lowered, within the limits of health and fire safety regulations, less fuel will be required in the incinerator. Also higher VOC concentration will provide a greater fraction of the total fuel requirement. Thus, increasing the VOC level not only reduces the size of the required incinerator and its capital and fixed operating cost, but also the fuel requirements. The degree of difficulty in retrofitting incinerators

to existing metal furniture facilities will vary depending on the age of the equipment and facility, and where the equipment is located.

In the past, most incinerators were fired with natural gas. Due to the energy shortages, some incinerators have been converted to No. 2 fuel oil, and more energy recovery methods have been used to reduce energy consumption.

Further technical details on the use of incineration may be found in Volume I, Section 3.2.2.[26]

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3.0 COST ANALYSIS

3.1 INTRODUCTION

3.1.1 Purpose

The purpose of this chapter is to present estimated costs for controlling solvent emissions from existing coating lines at metal furniture plants.

3.1.2 Scope

Estimates of capital and annualized costs are presented for controlling VOC (Volatile Organic Compounds) from application areas and curing ovens associated with electrostatic spray and dip coating lines applying a single coat to metal shelves. The control alternatives considered applicable to a coating line using the conventional solvent thinned coating and for which cost estimates are developed include:

Alternative I - Process Modification

Conversion to a coating system applying one of the following low solvent coating materials:

1. Higher solids (70% or above)
2. Waterborne
3. Powder

Alternative II - Exhaust Gas Treatment

Installation of hydrocarbon control equipment:

1. Carbon adsorption for application exhausts
2. Thermal incineration for oven exhausts

Detailed control costs estimates are developed for existing coating lines with annual production rates of 278,000 m^2/yr. and 4,000,000 m^2/yr. for electrostatic spraying and 650,000 m^2/yr. and 2,100,000 m^2/yr. for dip coating. The cost effectiveness (annualized cost (credit) per metric unit weight of VOC controlled) for the alternative control measures considered are estimated and graphically displayed for the range of production rates analyzed.

3.1.3 Use of Model Plants

The cost analysis provided in this chapter relies upon the use of model coating lines that are basically defined by an annual product coverage rate (square meters/year) for 1920 hours operation. In general, no attempt has been made to consider detailed design characteristics for the model lines in terms of process equipment requirements, line speed, etc. However, it was necessary to estimate the number of spray booths, required coating thickness, transfer efficiencies, oven and booth exhaust rates in order to estimate capital and operating costs for the control alternatives considered.

It is emphasized that model coating lines used in this analysis are particularly simple in that a one color single coat is applied to metal shelves. Analyzing multi-color coating systems is beyond the scope of this analysis although some general cost implications will be summarized later. Other factors influencing cost analyses of coating lines different than the models chosen will be covered in the discussion of the bases for model line cost estimates. Finally, although control cost

estimates based upon the model plant approach may differ with actual costs incurred, they are considered to be the best means of comparing the relative costs and cost-effectiveness of alternative control measures.

3.1.4 Bases for Capital Cost Estimates

Capital cost estimates are intended to represent the total capital required to purchase and install necessary control or process equipment. For coating lines converting to low solvent coatings, capital costs for control are generally incremental investments required to apply the different coatings. It has been assumed throughout the model cost analysis that existing pre-treatment and curing equipment will not require modification in going to low-solvent coatings.[1,2] This should not be interpreted to mean that such modifications are unnecessary in all cases. Rather, factors such as finish specifications and the condition of existing equipment will dictate how capital investments for actual lines will compare with the model estimates. The cost estimates provided were developed from EPA contractor studies and by contacting facilities that have implemented coating line conversions.[7,9,10] All capital costs are intended to reflect second quarter 1977 dollars.

3.1.5 Bases for Annualized Cost Estimates

Annualized cost estimates for the control alternatives considered are developed to reflect annual charges for capital required to purchase and install process equipment or control systems, operating and maintenance costs and miscellaneous recurring costs such as taxes, insurance and administrative overhead. Capital charges are calculated using the "capital

recovery factor" formula. Operating costs include costs for materials, utilities, labor and waste disposal. Net annualized costs for process changes, i.e. line conversions, are the incremental costs in going from the conventional solvent coating to the low solvent coating. As evidenced later in this chapter, some conversions are projected to result in net annualized savings while others appear to result in increased annual costs. The bases for these projected incremental costs or savings were provided in References 1 and 2. Again it is emphasized that these model coating line analyses are provided as a means of comparing the relative costs of alternative control measures. The area of estimating incremental annual costs (savings) for alternative coatings is one in which all coating suppliers have devoted considerable resources. Unsurprisingly, varying some key assumptions can alter the conclusions drastically. Annual coating material costs appear to have the greatest impact on annual costs (savings) when comparing different coatings. Differences in coating thickness requirements, transfer efficiencies, raw material costs and solids content all influence this cost element. Assumptions used in this analysis are provided later in Table 3-2 which lists technical assumptions associated with the model coating lines. General cost factors used to estimate annualized costs for the model coating lines are provided in Table 3-1. All annualized cost estimates are current.

3.2 CONTROL OF SOLVENT EMISSIONS FROM METAL FURNITURE SURFACE COATING - COST ESTIMATES

The technical parameters used in developing the control cost estimates

Table 3-1. COST FACTORS USED IN COMPUTING ANNUALIZED COSTS

I. Direct Operating Costs	
A. Materials (As purchased):	
- Alkyd conventional solvent coating (40% solids)*	$2.00/liter ($8/gal)
- Polyester high solids coating (70% solids)*	$3.70/liter ($14/gal)
- Alkyd Waterborne coating (40% solids)*	$2.40/liter ($9/gal)
- Epoxy powder coating	$3.30/kg ($1.50/lb)
- Electrodeposition waterborne (60% solids)*	$2.90/liter ($11/gal)
- Carbon	$2.20/kg ($1.00/lb)
2. Utilities	
- Electricity	0.03/kw-hr
- Natural gas	$1.90/thousand joules ($2.00/million Btu)
- Steam	$5.50/thousand Kg ($2.50/thousand lb)
- Boiler feed water	$0.13/thousand liters ($0.50/thousand gal)
3. Direct Labor	$10/man-hour
4. Maintenance Labor	
- Process modifications	$10/man-hour
- Add-on systems	0.02 x Capital Cost
5. Maintenance Materials	0.02 x Capital Cost
6. Waste Disposal	
- Electrodeposition	$0.008/liter coating ($0.03/gal)
- All others	$0.03/liter coating ($0.11/gal)
II. Annualized Capital Charges	
1. Depreciation and interest	0.1468 x Capital Cost
2. Taxes, insurance, administrative charges	0.04 x Captial Cost

* By volume

provided in Tables 3-3 and 3-4 are summarized in Table 3-2. Additional information regarding the expected range for many of these parameters is included in Chapters Two and Three of this document.

3.2.1 Electrostatic Spray Line

Capital and annualized costs for control alternatives applicable to electrostatic spray coating lines are presented in Table 3-3. Capital costs for converting lines to higher solids coatings (70% and above) or to waterborne coatings are related to application equipment modifications only. Sources estimated conversion costs at between $10,000-$15,000 per automatic station and about $1,000 for manual booths.[3,10] The above estimates change radically for waterborne if paint sources are not located close to application equipment and if stainless steel piping is required for paint recirculation systems. Additionally, as mentioned in Chapter Three, attempting to insulate the remote paint source configuration from ground to comply with OSHA requirements creates technical problems. Capital costs for converting to a powder coating are associated with installation at powder application and recovery systems. Since models considered are one color lines, only one recovery system is included in capital cost estimates. Multi-color lines with production rates comparable to model lines may realize higher costs for additional recovery systems in order to minimize the longer times associated with powder color changes. Capital costs for achieving VOC emission reductions comparable to low solvent coatings (i.e., 80% and greater) using exhaust gas treatment appear to be greater than line conversion costs.

Table 3-2. TECHNICAL PARAMETERS FOR MODEL COATING LINES

Electrostatic Spray Line	278,000 m^2/yr.	4,000,000 m^2/yr.
Number of Booths		
Automatic	1	4
Manual	2	2
Dry Coating Thickness, μm (mils)		
Conventional solvent	25(1)	25(1)
Higher solids	25(1)	25(1)
Waterborne	25(1)	25(1)
Powder	50(2)	50(2)
Transfer efficiencies	Same as Table 2 - Chapter 2	
Exhaust gas volumes, N m^3/sec (scfm)		
Oven(s)	0.24 (500)	3.30 (7000)
Booth(s)	4.25 (9000)	20.8 (44,000)

Dip Line	650,000 m^2/yr.	2,100,000 m^2/yr.
Dry Coating Thickness, μm (mils)		
Conventional solvent	25(1)	25(1)
Waterborne	25(1)	25(1)
Electrodeposition	17.5(0.7)	17.5(0.7)
Transfer Efficiencies	Same as Table 2 - Chapter 2	
Exhaust gas volumes, Nm^3/sec. (scfm)		
Oven	.94 (2000)	1.41 (3000)
Dip Tank	1.41 (3000)	3.76 (8000)

Table 3-3. CONTROL COSTS FOR MODEL EXISTING ELECTROSTATIC SPRAY COATING LINES

Alternative I - Process Change:	278,000 Square Meters/Year[a] (3,000,000 Square Feet/Year)				4,000,000 Square Meters/Year[a] (48,000,000 Square Feet/Year)			
	Baseline Costs	Incremental Costs for Conversion			Baseline Costs	Incremental Costs for Conversion		
	25% solids	Higher Solids	Waterborne	Powder	25% solids	Higher Solids	Waterborne	Powder
Installed Capital Cost ($000)	255[b]	15[c]	15[d]	60[e]	1,200[b]	62[c]	62[d]	317[e]
Direct Operating Costs (savings) ($000/yr)[f]	175	(6)	5	17	1,113	(81)	50	343
Capital Charges ($000/yr.)	48	3	3	11	224	12	12	59
Net Annualized Cost (credit)($000/yr)	223	(3)	8	28	1,337	(69)	62	402
Solvent Emissions Controlled (Mg/yr)[g]	NA	19	18	22	NA	305	285	345
Percent Emission Reduction	NA	86	80	97	NA	86	80	97
Cost(credit) per Mg of VOC controlled ($/Mg)	NA	(158)	444	1273	NA	(226)	217	1165

Alternative II - Exhaust Gas Treatment	(Oven) Thermal Incinerator with Primary Heat Recovery	(Spray Booth) Carbon Adsorption Solvent at Fuel Valve	Oven and Booth	(Oven) Thermal Incinerator with Primary Heat Recovery	(Spray Booth) Carbon Adsorption Solvent at Fuel Value	Oven and Booth
Installed Capital Cost ($000)[h]	36	92	128	150	500	650
Direct Operating Costs ($000/yr)[h]	5	17	22	31	82	113
Capital Charges ($000/yr)	7	17	24	28	93	121
Net Annualized Cost ($000/yr)	12	34	46	59	175	234
Solvent Emissions Controlled (Mg/yr)	4	15	19	64	241	305
Percent Emission Reduction (Total)	18	68	86	18	68	86
Cost per Mg of VOC controlled ($/Mg)	3,000	2,266	2,421	922	723	767

[a]One color system operating 1920 hours/year and coating metal shelves - single coat.

[b]Excludes metal pre-treatment equipment and dry-off oven costs for line (reference 1,2)

[c]Application and paint circulating equipment modifications (references 3, 10).

[d]Better insulation from ground to prevent electrical shock and corrosion protection (references 3,4)

[e]Booths and recovery system (reference 6).

[f]References 1,2.

[g]Mg = megagram = 1 metric ton

[h]References 1, 2.

Table 3-4. CONTROL COSTS FOR MODEL EXISTING DIP COATING LINES

Alternative I - Process Change:	650,000 Square Meters/Year[a] (7,000,000 Square Meters/Year)			2,100,000 Square Meters/Year[a] (22,500,000 Square Feet/Year)		
	Baseline Costs	Incremental Costs for Conversion		Baseline Costs	Incremental Costs for Conversion	
	25% Solids	Waterborne	EDP	25% Solids	Waterborne	EDP
Installed Capital Cost ($000)	105[b]	3[c]	124[d]	215[b]	5[c]	208[d]
Direct Operating Costs (Savings) ($000/yr)	135[e]	10[e]	2[f]	450[e]	17[e]	7[f]
Capital Charges ($000/yr)	20	1	23	40	1	39
Net Annualized Cost (credit) ($000/yr)	155	11	25	490	18	46
Solvent Emissions Controlled (Mg/yr)[g]	NA	25	38	NA	111	128
Percent Emission Reduction	NA	80	92	NA	80	92
Cost (credit) per Mg of VOC controlled ($/Mg)	NA	440	657	NA	162	359

Alternative II - Exhaust Gas Treatment	(Oven) Thermal Incinerator with Primary Heat Recovery	(Dip Tank) Carbon Adsorption Solvent at Fuel Valve	(Dip Tank) Oven and Tank	(Oven) Thermal Incinerator with Primary Heat Recovery	(Dip Tank) Carbon Adsorption Solvent at Fuel Valve	(Dip Tank) Oven and Tank
Installed Capital Cost ($000)[h]	93	150	243	119	270	389
Direct Operating Cost ($000/yr)[h]	8	6	14	12	9	21
Capital Charges ($000/yr)	17	28	45	22	50	72
Net Annualized Cost ($000/yr)	25	34	59	34	59	93
Solvent Emissions Controlled (Mg/yr)	18	18	36	63	63	126
Percent Emission Reduction (Total)	45	45	90	45	45	90
Cost per Mg of VOC Controlled ($/Mg)	1,388	1,888	1,638	540	936	738

[a]One color system operating 1920 hours/year and coating metal shelves - no primer.

[b]Excludes metal pre-treatment and dry-off oven costs (references 1,2).

[c]Existing tank cleaned and corrosion protection (reference 5).

[d]Existing solvent dip coating system replaced by EDP system (references 1,2,7).

[e]References 1,2.

[f]Reference 8.

[g]Mg = Megagram = 1 metric ton

[h]References 1,2.

Net annual savings appear possible by converting to higher solids coatings due mainly to the estimated lower applied film cost when compared to conventional solvent coatings.

As noted in Table 3-1, coating material costs for waterborne are slightly higher than solvent coatings for the same volume solids. This results in higher annual costs when converting to waterborne coatings. For lines converting to powder coatings some energy, waste disposal and direct labor savings were estimated.[1,2] However, as indicated in Table 3-2, it is assumed that metal furniture requires a coating thickness of 50 μm (2 mils) when coating with powders. This factor greatly diminishes any materials cost savings normally expected with powder coatings when compared to conventional solvent coatings.

In the case of incineration of oven emissions, annualized costs are mainly costs for fuel required to raise the temperature of the oven exhaust from 160°C to 760°C and capital charges. Annual costs for carbon adsorption of spray booth exhausts are slightly reduced (less than 2%) by crediting recovered solvent at fuel value. Large capital investments required for carbon adsorption systems are reflected in high capital charges. In general, net annualized costs for controlling VOC emissions from electrostatic spray coating lines appear to be lowest when converting to higher solids or waterborne coatings and greatest when combining incineration and carbon adsorption of oven and spray booth exhausts, respectively.

3.2.2 Dip Line

Capital and annualized costs for the control alternatives considered for existing dip lines are summarized in Table 3-4. The incremental capital costs for converting the dip line to waterborne appear to be small when compared to the baseline investment. Costs assume that the existing dip tank is used

and some corrosion protection is required. On the other hand, dip lines converting to the waterborne electrocoat will require significant investments when installing the electrodeposition application system. Capital costs for oven exhaust incineration and carbon adsorption of dip tank exhausts for the model dip lines are approximately two times greater than converting to electrodeposition.

Increased annualized costs for controlling dip coating lines by conversion to waterborne are primarily a result of higher material costs for the waterborne coating. For electrodeposition, lower applied film costs for the electrocoat material help over-ride increased electrical costs associated with the electrodeposition system.[1,8] Although incremental direct operating cost increases for the electrodeposition system appear to be minimal in Table 3-4, capital charges associated with the large capital investment requirements are much higher than waterborne conversion. Total annualized costs for incineration and carbon adsorption presented in Table 3-4 are about two times greater than incremental annualized costs for electrodeposition and about five times greater than waterborne annualized costs.

3.3 COST-EFFECTIVENESS

The cost-effectiveness of the alternative control measures considered for electrostatic spray and dip coating lines are summarized in Table 3-5. For electrostatic spray lines it appears to be more cost effective to reduce VOC emissions by converting to a low solvent coating, either waterborne or higher solids. Conversion to powder coating will result in the highest emission reduction achievable yet is not nearly as cost-effective as waterborne or

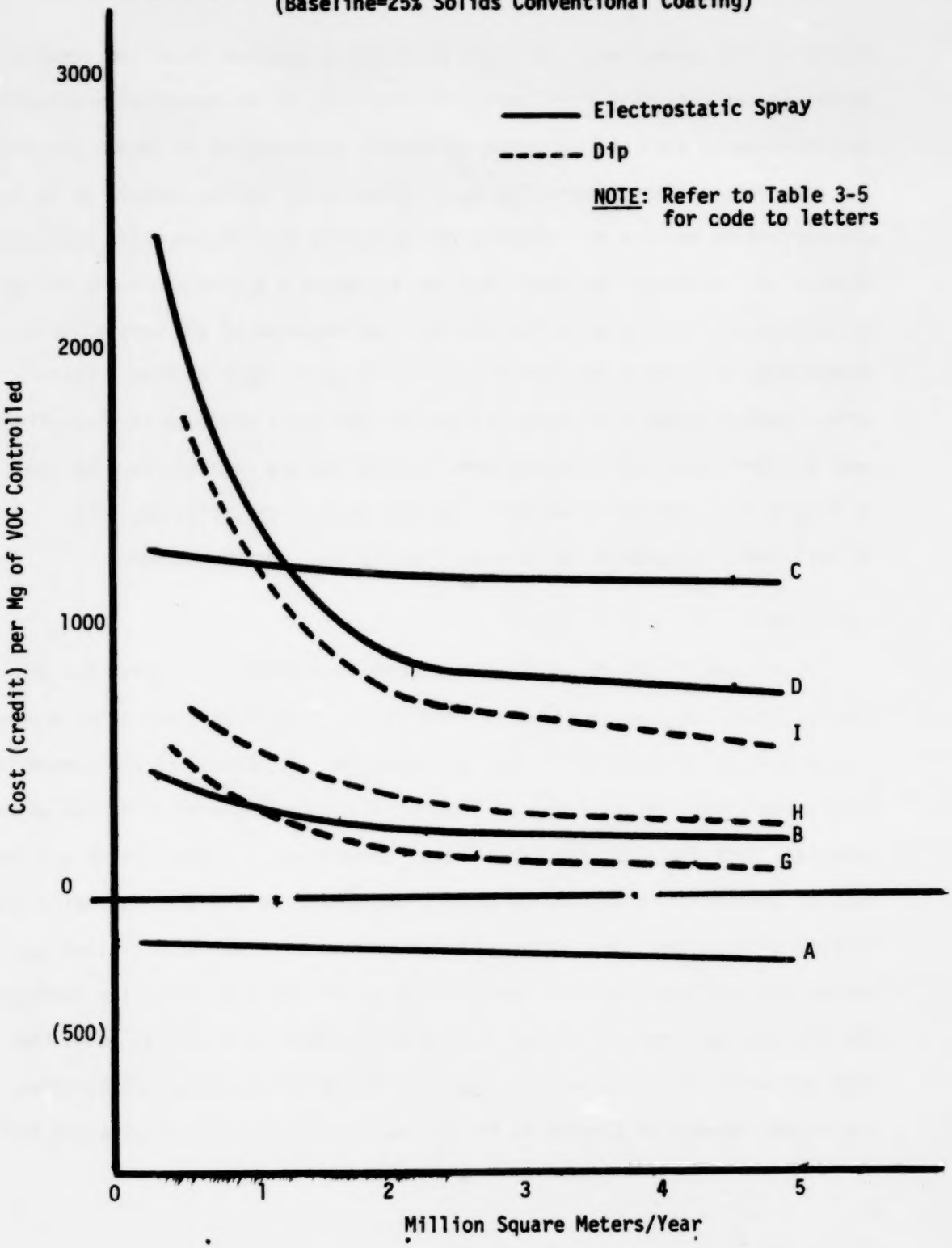
Table 3-5. COST EFFECTIVENESS OF ALTERNATIVE CONTROL METHODS

Spray Coating Line:	$/Mg of VOC Controlled		
	278,000 m^2/yr.	4,500,000 m^2/yr.	% Reduction in VOC
A. Conversion to Higher Solids Coating	(158)*	(226)	86
B. Conversion to Waterborne coating	444	217	80
C. Conversion to Powder Coating	1273	1165	97
D. Thermal Incinerator on Oven & Carbon Adsorber on Spray Booths	2421	767	86
E. Carbon Adsorber on Spray Booth	2266	723	68
F. Thermal Incinerator on Oven	3000	922	18

Dip Coating Line:	$/Mg of VOC Controlled		
	650,000 m^2/yr.	2,100,000 m^2/yr	% Reduction in VOC
G. Conversion to Waterborne	440	162	80
H. Conversion to Electrodeposition	657	359	92
I. Thermal Incinerator on Oven & Carbon Adsorber on Spray Booths (Dip Tank)	1638	738	90
J. Carbon Adsorber on Spray Booths (Dip Tank)	1888	936	45
K. Thermal Incinerator on Oven	1388	540	45

*Parenthesis indicates credit

Figure 3-1. Cost-Effectiveness versus Surface Area Coated
(Baseline=25% Solids Conventional Coating)



higher solids conversions. In fact, at higher production rates the results appear to indicate that it is more cost-effective to incinerate oven exhausts and treat booth exhausts by carbon adsorption than convert to powder coatings. For dip coating lines, converting to an alternative coating appears to be a more cost-effective measure for reducing VOC emissions than incineration and carbon adsorption. Although the model analysis estimates a 92% reduction in VOC by converting to electrodeposition, the cost per megagram of VOC controlled is higher than waterborne conversion over the range of sizes studied. Cost-effectiveness values from Table 3-5 and an additional estimate of cost-effectiveness for each application method were plotted and the results are displayed in Figure 3-1. Smooth curves drawn through the points depict how cost-effectiveness is expected to vary with square feet coated per year.

3.4 SUMMARY

Based upon the model analyses performed on electrostatic spray and dip coating lines applying finishes to metal shelves, VOC reductions of 80 percent or greater can be achieved at the least cost per unit weight of VOC controlled when using existing (modified) application equipment while applying low solvent coatings. For electrostatic spray lines, converting to higher solids coatings (70% or greater) or a waterborne coating appears to be the most cost effective control alternative. The latter alternative, however, may have limited application due to the technical and cost implications associated with some line configurations. For dip coating lines conversion to waterborne, where applicable, seems the most cost-effective alternative. Controlling VOC emissions by incineration and carbon adsorption appears to be the least cost-effective alternative for

the model lines considered.

Finally, it is stressed that the results of this analysis are intended only to serve as guidance in assessing the relative costs of alternative control schemes. Individual requirements and specifications of a particular coating line may require analysis when determining costs for that specific coating line.

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4.0 ADVERSE AND BENEFICIAL EFFECTS OF APPLYING TECHNOLOGY

4.1 POWDER COATINGS

There are several advantages obtained after a facility is converted to apply powder coatings besides the substantial reduction in emissions.

· There are almost none of the solid or liquid waste disposal costs or problems that are often encountered when using solvent-borne coatings.

· Powders do not require the purchase of additional solvents to control viscosity or to clean equipment.

· Conversion to powder coatings will reduce energy requirements of the spray booth because the large volumes of fresh air required for solvent-borne coatings are not required. (Although the lower explosive limit is higher than for solvent, the reduction in air volumes is possible mostly because the spray booth is not occupied.) By using an efficient particulate collector, the spray booth air may be recycled into the working area, further reducing energy usage for air conditioning or heating. It has been estimated that a 35-50 percent overall reduction in energy consumption can be achieved when a single coat application is replaced with one coat of powder, and a 55-70 percent reduction is possible when a two-coat application is replaced with a single coat of powder.[1]

· Powder coatings also have an advantage in providing good coverage of the metal piece and masking imperfections or welds in the metal.

· Although powder overspray can be reclaimed at about 98 percent efficiency, not all the reclaimed powders can be reused. Reclaimed powder containing a buildup of powder fines will have to be discarded, and the larger and heavier granules will have to be reprocessed again before they are suitable for reuse.[2,3]

There are disadvantages encountered when applying powder coatings.

· All application equipment, spray booths and associated equipment (and often ovens) used for liquid systems must be replaced. This will then limit the coating flexibility of the metal furniture manufacturer because he will only be able to apply powders.

· Coating film thickness of less than 2 mils has not been successfully obtained with powders on a production line basis.

· Color changes for powder require about half an hour downtime, Metal furniture facilities requiring numerous color changes during the day would have to greatly curtail production capacity. Color changes may be shortened if the powders are not reclaimed in their respective colors resulting in a coating usage efficiency of about 50 to 60 percent. Those facilities which apply many colors but can schedule their operations to run a single color for a given time period may still find powder an economically acceptable alternative.

· No one can yet provide the so-called metallic coatings in powder.

· Color matching during manufacturing of powder is difficult.

· Powder films have appearance limitations.

· Recesses are difficult to cover effectively due to the Faraday caging effect.

· Excessive humidity during storage or application can affect the performance of powder.

· Powder coatings are also subject to explosions,as are many particulate dusts.[4]

4.2 ELECTRODEPOSITION

Several other advantages, in addition to reduced VOC emissions, accrue from converting to electrodeposition.

· The major one is good quality control as a consequence of the fully automated process.

· It provides a very high transfer efficiency.

· It also provides excellent coating coverage and corrosion protection because the paint particles penetrate into the smallest recesses. (However, because the coverage is so uniform, electrodeposition does not mask imperfections in the substrate as well as other application techniques).

· The low solvent content permits lower ventilation rates resulting in reduced energy consumption.

· The dry off oven that normally follows the pretreatment step is no longer required although an additional rinse with deionized water is essential.

· Conversion to electrodeposition may also result in lower insurance costs because of reduced fire and toxicity hazards.

There are several disadvantages to the electrodeposition process.

· One is that it requires a unique type of application equipment. As a result, electrodeposition can be capital intensive when used on small scale production lines.

· If the hooks which hold the metal furniture pieces are not properly cleaned or hung, the electrical contact may be faulty and the coating will not adhere to the metal.

· Conversion to electrodeposition coating will increase electrical consumption. The amount, however, will depend on the former application system, size of the electrodeposition bath, type of furniture pieces coated, and thickness of the coating. Energy is required for the coating system, refrigeration (to overcome the heat generated by the electrical process), to circulate the bath, and purification of the bath. If a spray operation is

replaced by electrodeposition, some credit may be allowed for decreased solid and liquid wastes and the reduced energy requirements attributable to elimination of the spray booth.

4.3 WATER-BORNE COATINGS

There are several advantages to converting to water-borne coatings.

· The greatest is that existing equipment, whether for spray, flow, or dip coating, can be used. (Some parts of the coating equipment, however, may have to be protected from corrosion).

· Water-borne coatings may be thinned with water, and coating equipment can be cleaned or flushed with water rather than organic solvent. Unlike with organic coatings, however, water-borne coatings must be cleaned off application equipment when still wet since they are not soluble in their carriers when they become dry making cleanup with organic solvents necessary.

· A potential disadvantage of water-borne coatings is that energy consumption may increase because some water-borne coatings must be flashed off under controlled humidity, and the ovens may have to be lengthened to several stages to compensate for the slower evaporation rate. However, this energy increase is partially offset by the reduced oven exhaust and perhaps the lower curing temperature typical of many water-borne coatings.

· The water-borne coating is more sensitive to temperature and humidity, both during application and flashoff. The flashoff air circulation may need to be increased to allow a uniform evaporation rate of water during high and low humidity conditions.[5]

· Disposal of solid or liquid waste may be difficult.

· In dip or flow coating processes, an additional rinse may be required to avoid contamination of the coating bath.

· Overspray from water-borne does not harden as rapidly making sludge handling more difficult.

· Proper pretreatment is critical to prevent flash rusting of metal furniture.

4.4 HIGHER SOLIDS COATINGS

Higher solids coatings can be applied with existing spray equipment. These coatings are presently limited to about 65 volume percent solids, although research is being done; both on high solids (65-80 percent) coatings and on improved application equipment. Conversion to higher solids coatings can reduce energy requirements. Air flow in the spray booth can be reduced because less organic solvent is applied for each dry mil of coating. The oven energy requirements may also be reduced. Solid and liquid waste may decrease since less coating is applied per dry mil. However, the tackiness of some high-solids coatings may make cleanup more difficult.[6] Although the solvent content is reduced, thus reducing the level of toxicity, there is a potential health hazard associated with isocyanates used in some high-solid, two-component systems.

4.5 CARBON ADSORPTION

There are no metal coating facilities known to use carbon adsorbers to reduce VOC from application and flashoff areas. This technology, however, is technically feasible for such applications and is well documented. A potential disadvantage is that it will increase the requirements for electrical and fuel energy. The amount will depend on application, size of adsorber, and concentration of the organics entering the carbon bed. Any decrease in air flow and accompanying increase in VOC concentration from the coating application and flashoff areas will reduce the energy demands.

The amount of solid and liquid waste generated by use of a carbon adsorber will vary. Emissions from flow and dip coating operations do not contain particulate matter and will not require filtration or scrubbing. Emissions from spray booths, however, may require some filtration due to overspray particulate in the gas stream. Water miscible solvents pose a water treatment problem if regenerated steam is condensed and discharged untreated. However, this can be solved by incinerating the steam (or hot air)and solvent together, or by stripping the condensate and disposing of such solvents. This will increase the costs and energy consumption of the carbon adsorption system.

4.6 INCINERATION

The most common and widely applicable technique used for the reduction of organic emissions is incineration. However, one potential disadvantage is the oxidation of sulfur (if fuel oil is used) and nitrogen compounds. Another is the incremental fuel requirement unless heat recovery is used. The use of "primary"(preheat of the oven exhaust near incineration temperature) and"secondary"(use of incinerator exhaust for other energy using processes) heat recovery will reduce overall energy consumption and perhaps reduce overall energy usage if there are enough areas where secondary heat may be utilized. Table 4-1 shows the potential fuel savings based on tube and shell exchangers. Some examples (besides preheating the oven exhaust to the incinerator) where the hot incinerator exhaust may be used are as follows: oven makeup air, boilers, a heat source for the cleansing process, and plant heat. Greater heat recovery efficiencies (85-90 percent) with other types of heat exchangers would make incineration of low VOC concentration streams attractive.

TABLE 4-1

BURNER REQUIREMENTS FOR INCINERATORS IN 10^6 BTU/HR[a,b] 7/

NON-CATALYTIC INCINERATORS	5 percent LEL	15 percent LEL
No Heat Recovery		
5000 scfm	5.82	4.05
15,000 scfm	17.48	12.16
30,000 scfm	34.95	24.31
38% Efficient Primary Heat Recovery		
5000 scfm	3.32	1.56
15,000 scfm	10.09	4.73
30,000 scfm	19.97	9.38
Primary and 55% Efficient Secondary Heat Recovery		
5000 scfm	1.42	-0.34
15,000 scfm	4.40	-0.66
30,000 scfm	8.67	-1.82
CATALYTIC INCINERATORS		
No Heat Recovery		
5000 scfm	1.69	1.69
15,000 scfm	5.07	5.07
30,000 scfm	10.14	10.14
38% Efficient Primary Heat Recovery		
5000 scfm	0.79	0.26
15,000 scfm	2.38	0.77
30,000 scfm	4.76	1.54
Primary and 55% Efficient Secondary Heat Recovery		
5000 scfm	-0.21	-1.07
15,000 scfm	-0.62	-3.22
30,000 scfm	-1.24	-6.46

a) Based on 300°F oven outlet temperature; 1400°F outlet temperature for non-catalytic and 600°F inlet temperature for catalytic incinerators.

b) (-) indicates net overall fuel savings.

4.7 REFERENCES

1. "Economic Justification of Powder Coating. Powder Finishing World. Pages 18-22, 4th quarter, 1976.

2. LeBras, Louis R., Technical Director, PPG Industries, Inc., Pittsburgh, Pa. Letter to Vera Gallagher in comment of this document. Letter dated September 22, 1977.

3. Dornbos, David L. Sr., Steelcase, Incorporated, Grand Rapids, Michigan. Letter to Vera Gallagher in comment of this document. Letter dated August 31, 1977.

4. Op. Cit. LeBras

5. "Water-Borne Flow Coat and Dip," Products Finishing. Pages 73-76. February 1977.

6. "Question Corner," High-Solids Coatings, Volume I, No. 3. July 1976.

7. Combustion Engineering Air Preheater. Wellsville, New York, Report of Fuel Requirements, Capital Cost and Operating Expenses for Catalytic and Thermal Afterburners. EPA Contract Report No. EPA-450/3-76-031. September 1976.

5.0 MONITORING TECHNIQUES AND ENFORCEMENT ASPECTS

This chapter discusses the recommended emission limit, the monitoring techniques and enforcement aspects of low polluting coatings and add-on control equipment.

As stated in the preface, there is no universal VOC emission control technique applicable for the industry as a whole because of the variety of metal furniture products manufactured. However, metal furniture facilities have certain similarities which permits grouping them for use of certain control techniques. For example, if a facility has no difficulty with Faraday caging, applies a limited number of colors, can run a single color for a given time period, and a coating film thickness of greater than two mils is not objectionable, powder could be the best control technique. If a facility runs only a few colors on a large production basis, electrodeposition would be the best control technique. However, if a facility must color match or change colors frequently, water-borne or higher-solids coatings would be the best choice. The recommended emission limit(3.0 lbs of organic solvent per gallon of coating, less water), as stated in the Preface,is based on the application of water-borne or higher solids coatings. Sample calculations to verify compliance with this emission limit are shown in Appendix A.

Previous control regulations for VOC have included limitations on the reactive organic solvent or have stipulated that a minimal reduction be achieved through add-on control equipment. While either approach is acceptable, maximum solvent content is a more practical basis for those surface coating operations where use of low-solvent coatings will generally be the compliance technique.

For metal furniture industries, it is recommended that emission limitations be expressed in terms of organic solvent content since these values can be determined with relatively simple analytical techniques.

Limitations in VOC may be expressed in terms of mass or volume and may be based on the entire coating (including organic solvent) or only on paint solids. In this guideline, limitations are expressed as the allowable mass of organic solvent per unit volume of coating (kgs per liter of coating or lbs per gallon of coating) as it is delivered to the coating applicator. Water in the coating is subtracted. The principal advantage of this format is that enforcement is relatively simple. Field personnel can draw samples and have them analyzed quickly. A disadvantage is that the relationship between the solvent fraction and organic emissions is not linear. If the solvent content is expressed in terms of mass of organic solvent per unit volume of paint solids (kgs per liter of solids or lbs per gallon of solids), the disparity disappears. The relationship is linear and more readily understood e.g., a coating containing 2 lbs of organic solvent per gallon of solids releases twice as much organic solvent as one of 1 lb per gallon. The disadvantage of this format, however, is that the analytical methods are more complex. Appendix A in "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles and Light Duty Trucks" presents ASTM methods for determination of the pounds of organic solvents per gallon of coating (minus water).

Other options such as pounds or gallons of organic solvent per pound of coating are generally less desirable although they may be entirely appropriate for a given industry. Basing limitations on the mass of coating or paint

solids is not recommended because the specific gravity of coatings tends to vary widely with the degree and type of pigment employed. Highly pigmented paints have much greater density than unpigmented clear coats or varnishes.

This limitation for coatings assumed the facility merely converts from use of an organic-borne coating to a coating low in organic solvent. It does not consider any small or significant reduction in VOC emissions which may result from a decrease in film thickness or an increase in transfer efficiency of a coating. One example of such reduction may be where a facility is applying a conventional coating at 1.2 mils film thickness, and converts to a coating containing less organic solvent than the conventional coating but which does not quite meet the recommended emission limit. However, if the new coating has better hiding power and can be applied at only 0.8 mils film thickness, the decrease in film thickness can still result in a proportional reduction in VOC emissions as compared to a coating which meets the recommended emission limit. Other examples would be if a facility converts from a manual conventional spray application (at a transfer efficiency of 40-70 percent) to an automated electrostatic spray system (at a transfer efficiency of 70-90 percent), or from any spray system to a flow or dip coat system (at a transfer efficiency of at least 90 percent). Some incremental reduction in VOC emissions will be realized. This reduction in VOC content can be included in the overall system to provide the equivalent reduction in emissions.

In those few facilities where add-on control equipment is a more likely option, it may be more appropriate to state emission limits in terms of control efficiency across the incinerator, adsorber, etc. Where limitations

are expressed only in terms of the coating content, it will be necessary to determine mass emissions from the control system and relate them to the quantity of coatings applied during the test period. It is often difficult to determine the consumption of coatings during any given period and to determine the amount of organic solvent directed to the control device. Chapter 5 of "Control of Volatile Organic Emissions from Existing Stationary Sources - Volume I: Control Methods for Surface Coating Operations" presents test methods for add-on control devices. When add-on type devices are selected as the compliance method, the air pollution control agency should require that the coating lines be equipped with an approved capture device to assure effective control. The capture system will likely have to be custom designed to accommodate the plant-to-plant variables which affect performance. When reviewing the design of such a system, however, the air pollution control official must consider requirements imposed by the Occupational Safety and Health Administration and the National Fire Prevention Association.

Some coatings will emit a greater amount of VOC than merely its solvent content. This incremental VOC may come from three possible sources. The first is the possibility that some of the monomer may evaporate. Also, if it reacts by the condensation polymerization, the evolution of by-product compounds may be a compounding factor. Finally, it has been reported that the industry is using increasing quantities of "blocking agents" which are released from the polymer matrix during the curing process.

There are now no approved analytical methods certified by the agency for determining the quantity of VOC emitted by such reactions, although certainly the organic mass emission rate could be determined by expensive

and sophisticated analytical techniques. The more practical means of quantifying the contribution of the polymerization reaction to the overall emission problem would be by contacting the manufacturer of the coating. Certainly, his knowledge of the fundamental chemical mechanisms involved would allow calculation of an emission rate based on the chemical reaction.

This emission will occur during the cure (if at all) which is usually temperature initiated by the oven. If the oven is controlled by an incinerator, then verification of the efficiency of the device should be sufficient to assure compliance with the coating regulation.

APPENDIX A

SAMPLE CALCULATIONS OF CONTROL OPTIONS

This appendix aids the local agency in determining if a coating proposed for use by a metal furniture facility will meet the recommended emission limit of 0.36 kilograms of VOC per liter of coating applied, (3.0 lbs/gal) excluding any water that the coating may contain. The purpose of excluding water is to preclude compliance through dilution with water. This appendix also explains how to compare the actual VOC emissions from a facility regardless of the type of low-polluting coating or add-on control device used.

The purpose of all coating operations is to cover a substrate with a film that provides both corrosion resistance to the substrate and esthetic appeal. Therefore, the rational basis for specifying an allowable VOC emission limit would be in units of coating volume (e.g, grams of VOC per square meter (lbs/sq.ft) per unit thickness of film). However, the complexity of any analytical method which would provide a measurement of the volume of a cured coating precluded this approch. As a compromise, the recommended limitations were developed in kilograms (lbs) of VOC per unit volume of uncured solids and organic solvent. Mathematically, then, the emission factor (ef) for a coating would be expressed as:

$$(1)\quad ef = \frac{(\text{volume fraction organic solvent})(\text{average organic solvent density})}{\text{volume fraction of solids} + \text{volume fraction of organic solvent}}$$

or

$$(2)\quad ef = \frac{(\text{volume fraction organic solvent})(\text{average organic solvent density})}{1 - \text{volume fraction of water}}$$

The following examples show the use of these equations to determine the emission factor for both organic solvent-borne and water-borne coatings.

CASE 1: Determine the emission factor for an organic solvent-borne coating which contains 40 percent organic solvent.

$$\text{Therefore: } ef = \frac{(.40)(0.88 \text{ kg/liter}^*)}{1 - 0}$$

$$= 0.35 \text{ kg/liter } (2.94 \text{ lbs/gal})$$

Since the emission factor is less than the recommended limit of 0.36 kg/liter (3.0 lbs/gal), this coating is in compliance.

CASE 2: Determine the emission factor for a water-borne coating containing 75 percent solvent.

Since 80 percent of the solvent is water, the respective volumes of water and organic solvent may be calculated as shown:

Volume water= .80 x .75 liter = .6 liter

Volume organic solvent= 0.75 liter - .6 liter = .15 liter

$$\text{Therefore: } ef = \frac{(0.15)(0.88 \text{ kg/liter}^*)}{1 - 0.6}$$

$$= 0.32 \text{ kg/liter } (2.64 \text{ lbs/gal})$$

This coating also has an emission factor less than the recommended limit and would comply.

The level of control represented by 0.36 kg/liter of coating (3.0 lbs/gal) less water can also be achieved with a conventional high organic solvent coating if suitable add-on control equipment is installed. However, this method of determining the equivalvent emission limit factor is not as straightforward as the previous two cases and must also consider the volume of solids in the coating.

*This density is considered typical and is equal to 1.36 lbs/gal.

CASE 3: Determine the emission factor for a conventional organic-borne coating containing 75 percent organic solvent.

$$\text{Therefore: } ef = \frac{(.75)(.88 \text{ kg/liter}^*)}{1-0}$$

$$= 0.66 \text{ kg/liter (5.5 lbs/gal)}$$

However, this liter of coating contains only 0.25 liter (gallon of solids whereas the coating which represents the recommended emission limit of 0.36 kg/liter (3.0 lbs/gal) contains 0.60 liter (gallon) of solids. (This can be back calculated from the recommended emission limit in this manner.)

$$\text{i.e. } 0.36 = \frac{(x)(0.88 \text{ kg/liter})}{1-0}$$

$$x = 0.40 \text{ volume percent organic solvent.}$$

Therefore fraction of solids = 1 - x = 0.60

On a unit volume of solids basis, the conventional coating contains:

$$\frac{0.66 \text{ kg organic solvent}}{0.25 \text{ liter solids}} = \frac{2.64 \text{ organic solvent}}{\text{liter solids}} \qquad \frac{22 \text{ lbs VOC}}{\text{gal. solids}}$$

And the recommended limit reference coating contains

$$\frac{0.36 \text{ kg organic solvent}}{0.6 \text{ liter solids}} = \frac{0.6 \text{ kg organic solvent}}{\text{liter solids}} \qquad \frac{5 \text{ lbs VOC}}{\text{gal solids}}$$

Consequently, in order for the conventional coating to emit no more VOC than the reference coating, the add-on control device must capture and destroy (or collect) 2.04 kg of solvent per liter of solids applied (2.64 - 0.6). This will require a control system that is at least 78 percent efficient. Since the add-on control devices can often operate at 90 percent efficiency or greater, the agency must insure that at least 85 percent of the VOC emitted by the coating is captured and delivered to the add-on control device. Since it will normally not be practical to attempt the complex analytical program essential to develop a material balance around the coating application and flashoff areas and ovens, the agency will normally certify an acceptable capture system based on good engineering practice.[1]

APPENDIX A REFERENCE

1. Young, Dexter E., Environmental Protection Agency, memorandum concerning requirements for ventilation of spray booths and ovens. Dated March 10, 1977.